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"Experimental Investigation of the Impact Characteristics on Non-Metallic Materials"

Annual Report No. 1

June 6, 1966 - May 31, 1967

Contract No. NAS8-20346

Control No. DCN1-6-28-0014(1F)

Prepared by: Dr. James L. Hill
Associate Professor of
Engineering Mechanics

For: University of Alabama
Bureau of Engineering Research
University, Alabama

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This report was prepared by the University of Alabama under Contract No. NAS8-20346 "Experimental Investigations of Impact Characteristics on Non-Metallic Materials", for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under technical direction of Research Projects Laboratory, George C. Marshall Space Flight Center, Mr. Stanley A. Fields acting as project manager.

ABSTRACT

Characteristics of craters produced in targets of volcanic origin by aluminum projectiles are described. The targets are basalt and pumice in both solid and granular form. The projectiles are .308 caliber aluminum cylinders whose weights are between 12 and 30 grains and the projectile velocities are between 2500 and 5000 fps.

The craters in the solid basalt are shallow and large in diameter. This is due to the shearing out of large spalls by the highly crushed material that is moving out from in front of the projectile.

The solid pumice craters differ in that the highly crushed material in the central zone only crushes the pumice more around the central zone as it moves from in front of the projectile. This results in a crater that has a small entry hole that goes into a larger cavity.

In the ground pumice (62-250 micron), the craters are double conical around a central burrow. Craters in finely ground basalt (62-250 micron) are nearly hemispherical at the bottom with very steep walls and have a slightly raised rim.

INTRODUCTION

Some experimental investigation of the characteristics of impacting materials of volcanic origin by aluminum projectiles has been performed. The purpose of these experiments was to obtain impacts in materials that may be similar to the lunar surface with projectiles whose velocities were less than the lunar escape velocity (about 7900 fps). By comparing the crater characteristics obtained in the laboratory with the crater characteristics of secondary impacts on the lunar surface, it may be possible to draw some useful conclusion about the nature of the lunar surface. Gault, Quaide and Oberbeck (1)[1] indicate that the craters from some secondary impacts can be identified on the lunar surface from the Ranger photographs.

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[1]The numbers in parenthesis indicate references listed at the end of this report.

EXPERIMENTAL APPARATUS

The impact chamber system is shown schematically in Fig. 1. The projectile accelerator (a .378 magnum action with a .308 caliber barrel) is mounted in the gun tube at the top and the projectile is fired downward through the baffle chamber, upper tube, top observation section, lower tube, lower observation section and into the target in the impact chamber. The baffle chamber, upper tube, and lower tube are double walled so that liquid nitrogen can be circulated around them.

The velocity of the projectile is obtained by measuring the time elasped for the projectile to pass from the top observation section to the lower observation section. As the projectile passes through the observation sections it opens circuits by breaking a fine wire grid placed in its line of flight.

The target and its support are raised and lowered using a hydraulic jack.

GENERAL DISCUSSION OF EXPERIMENTS

The target materials were either basalt or pumice. Both solid and granular basalt and pumice were used. The solid basalt samples evidenced stratification. The solid targets were blocks about four inches thick and very irregular in their plan. The granular samples were contained in stainless steel containers 10.0 inches in diameter and 6.0 inches deep.

The projectiles were accelerated by a conventional 0.308 caliber rifle. The cartridge was 0.378 magnum caliber. There are baffles and cryogenic surfaces in the system to trap the products of combustion of the powder. However, the baffles and cryogenic surfaces are not trapping all of these gases. This is indicated by an increase of moisture content of the surface layer in the granular samples during firing. Also a dynamic pressure rise in the impact chamber occurs that results in the steady state pressure in the system raising about one half of an inch of mercury. The procedure used in making a shot was as follows:

1. Place the sample into the impact chamber.
2. Load the projectile accelerator.
3. Evacuate the system to a vacuum of less than 100 microns of mercury.
4. Fill the shrouds around the baffle chamber, upper and lower tubes with liquid nitrogen. This usually causes the pressure to drop 5 to 10 microns of mercury.
5. Fire the projectile accelerator and impact the target.
6. Wait until the liquid nitrogen boils away.
7. Raise the pressure in the system to atmospheric pressure.
8. Carefully remove the sample from the chamber.

9. Photograph the impacted sample and make observations about the sample.

10. The sample and ejecta are stored for futher study.

Several difficulties were encountered and overcome during this period. This resulted in only 17 tests being completed. The first of these difficulties was a system to measure the velocity of the projectile. The initial idea was to use timing tape which consisted of 35 mm film that had a conducting strip painted on it. As the projectile pierces the first tape a circuit is broken to provide a signal to start the timer and then as it pierces the second tape the timer is stopped. Check-out shots on this system gave inconsistent results. An optical system that used photocells to provide the starting and stopping signals was designed. This system never proved operable. Finally a simple system that uses grids of fine wire in place of the timing tape was found to give consistent results.

Next it was found that some ammunition gave greatly varying velocities when fired vertically and horizontally. This evidently is due to the way the powder lies in the case and the effect of this on the efficiency of combustion of the powder. The velocity obtained from a vertical shot was always lower than that obtained in a horizontal shot using identical ammunition. For some ammunition the vertical velocity was 30 percent lower than the horizontal. By using magnum primers and wadding to hold the powder aginst the primer the difference was reduced to about 5 percent.

The initial tests were made on solid basalt block with 30 grain projectiles. These projectiles always shattered the sample so badly that no usable results were obtained. By reducing the mass of the projectiles to less than 15 grains most of the impacts did not shatter the basalt samples.

RESULTS

All impacts were made at normal incidence. The main experimental results obtained were crater characteristics as a function of target material and projectile momentum and kinetic energy. The projectiles were made of aluminum alloy 6061-T6. The results will be grouped according to target material.

Solid Basalt Targets

In all, nine tests were made where the targets were solid basalt. In four of these tests the samples were so badly shattered that no usable crater results were obtained. In another test the sample evidently had a surface of discontinuity almost parallel to the top face and about 0.27 inches below the central impact zone. This resulted in the crater being too shallow and too large in plan view since all the material on one side of the impact between the top surface and the surface of discontinuity was evacuated.

The photograph in Fig. 2 is a close up view of a typical crater formed by normal impact on solid basalt.

Fig. 3 is a sketch of the probable sequence of events in the cratering process in basalt. The central zone of the crater is very rough and is evidently the result of crushing action of the oncoming projectile. The crushed material under the projectile is forced to the sides exerting large pressures on the wall of the burrow as it tries to move out from under the projectile. This pressure causes the spalls to shear off from the target material to open up the shallow cup that is the largest part of the crater. Maurer and Rinehart (2) describe similar craters produced in granite. The spalls were readily identified and could easily be fitted back in place in the crater.

In Fig. 4 is presented the depth of the craters in basalt samples as a function of the momentum of the impacting projectile. The four usable data fit a straight line on this log-log plot quite well. This implies an emprical relation such as

$$p = C(mv)^b$$

exists between penetration, p, and projectile momentum, mv. For basalt blocks, aluminum projectiles with velocities between 2000 and 5000 fps the constants C and b have the values C = 1.075 and b = .643. Then penetration is measured in inches and momentum in lb-sec.

Fig. 5 shows volume of the craters as a function of the linear momentum on a log-log plot. This does not indicate any simple emprical relation between these parameters.

Solid Pumice Targets

Two tests were made on pumice targets. The sample in the first test shattered while the other test produced a crater believed to be typical of impacting pumice of this type with the type of projectiles used. A photograph of the crater is shown in Fig. 6 and an approximate cross section of the crater is presented in Fig. 7. The samll entry hole and larger cavity are typical of craters in low density crushable targets (3).

The projectile that impacted this pumice target weighed 13.2 grains and had a velocity of 3990 fps. This gave the projectile a linear momentum of 0.234 lb-sec and a kinetic energy of 466.2 ft-lb at impact. The crater was 1.62 inches deep and had a volume of 1.56 cubic inches. After the impact a large part of the crater was still filled with crushed pumice.

Granular Basalt Targets

Three test were made in ground basalt targets. The granular material was contained in stainless steel containers whose inside dimensions are 10.0 inches in diameter and 6.0 inches deep. The shape of the crater differs greatly with particle size of the target. The granular material in these three experiments were of three different size distributions: 62-125 microns, 125-250 microns and 500-1000 microns.

The crater produced in the 500-1000 micron target consisted of a small central crater that was shallow and dish shaped that opened to a much larger shallow crater which ended in a raised rim very close to the edge of the container. A sketch of this crater is shown in Fig. 8. The raised rim is probably due to the container. The projectile that produced this crater weighed 29.8 grains and the velocity of it was 3680 fps.

The craters obtained in the 62-125 micron and 125-250 micron targets were very similar. A photograph of the crater in the 62-125 micron target is shown in Fig. 9. A plaster of paris mold of this target after impact was made. The depth of the crater was 3.05 inches and the volume of the crater was 45.89 cubic inches. This crater was produced by a projectile that weighed 13.2 grains and had a velocity of 5140 fps. In Fig. 10 is shown a sketch of a cross-section of this crater with some interesting dimensions. Notice the near vertical sides and the raised rim. Due to the distance from the walls of the crater to the walls of the container the rim is probably not the result of the container. Notice also in the photograph in Fig. 9 that the granular material collected together into small modules inside the crater, and there is at least one outside the crater. Some evidence of crumbling and slumping of the near vertical walls of the crater is shown in Fig. 9. All the features described about this crater were also found in the crater in the 125-250 micron target.

Granular Pumice Targets

Two test were performed using granular pumice as targets. The two samples of ground pumice were sized 62-125 microns and 125-250 microns. The craters produced in both targets were very similar.

A photograph of the top view of the crater obtained in the 125-250 micron target is shown in Fig. 11. A plaster of paris mold was also made of this crater. From the mold a cross section of the crater was obtained and is presented in Fig. 12. The most interesting feature of these craters is their double conical character. The very central zone of impact is highly pulverized and there is a burrow with vertical sides with overhangs, this opens out into an irregular conical crater whose sides are inclined about 50° with the horizontal then ends in an annular region that goes into another conical surface that is much more regular than the inner cone. The sides of the larger outer cone are inclined at an angle of 35° with the horizontal. This cone ends in a raised rim but the rim is so close to the edge of the container it is difficult to determine if the edge of the container is the cause of the rim.

For the 125-250 micron target the dimensions of the crater are shown on Fig. 12. The projectile weighed 14.1 grains and its velocity was 3610 fps at impact. The total volume of the crater was 33.69 cubic inches. There was a very weak crust formed over almost the entire surface of the inner and outer cones. It was very smooth, and broke up when the sample was handled. Concentric ripples in this crust formed on parts of the surface of the outer cone. Also present in the surface of the outer cone was a set of rays. Three rays are well defined in one 90° sector of this surface as shown in Fig. 11.

CONCLUSIONS AND RECOMMEDNATIONS

The experiments performed indicate the nature of craters that develop in the four types of target materials when impacted by aluminum projectiles weighing between 12 and 30 grains with velocities between 2500 and 5000 fps. The crater in the solid basalt is shallow and large in diameter due to the spalls that are sheared out of the way by the material of the central zone as it moves from in front of the incoming projectile. The solid pumice is different in that the material in the central zone Only crushes the material around it in all directions as it is pushed by the projectile. This is possible because of the porosity of the pumice. Craters in ground basalt are nearly hemispherical at the bottom, have very steep walls and slightly raised rims. In ground pumice the craters are double conical in nature about a burrow where the material is highly pulverized by the impact. This burrow has very irregular walls, near vertical with overhangs.

Much more data must be taken so that the way impact characteristics vary with the pertinent parameters can be ascertained. Now that the system is operable a much larger number of tests will be made in the next report period.

Since the provisions to trap the products of combustion of the gun powder are not satisfactory, ways of improving this situation should be conceived and implemented. First, the baffles and cryogenic surfaces should be evaluated as to their effectiveness in reducing the strength of the muzzle blast. Based on these findings, ways and means of further reducing the muzzle blast must be conceived and implemented.

So far, all results have been on the crater characteristics of impacting non-metallic targets. Also of interest is the behavior of the target and the ejecta during impact. To gather this data, photographs must be made of the impact process. Present plans are to focus a camera on a plane that is perpendicular to the target that includes the line of flight of the projectile. The chamber will be optically sealed and the lens of the camera opened. The projectile will break a wire at a preset height above the target. This will trigger a single flash from a stroboscope. The duration of the flash is 3.0 microseconds. The flash is culminated in the focus plane by a cylindrical lens. This should produce photographs images of the ejecta that are traveling in the plane of focus. The ejecta images will actually be short streaks. The length of the streaks will indicate their velocity and the directions of the streaks will be the same as the directions of the ejecta. For example, a particle of ejecta with a velocity of 10,000 fps would produce a streak 0.36 inches in length.

REFERENCES

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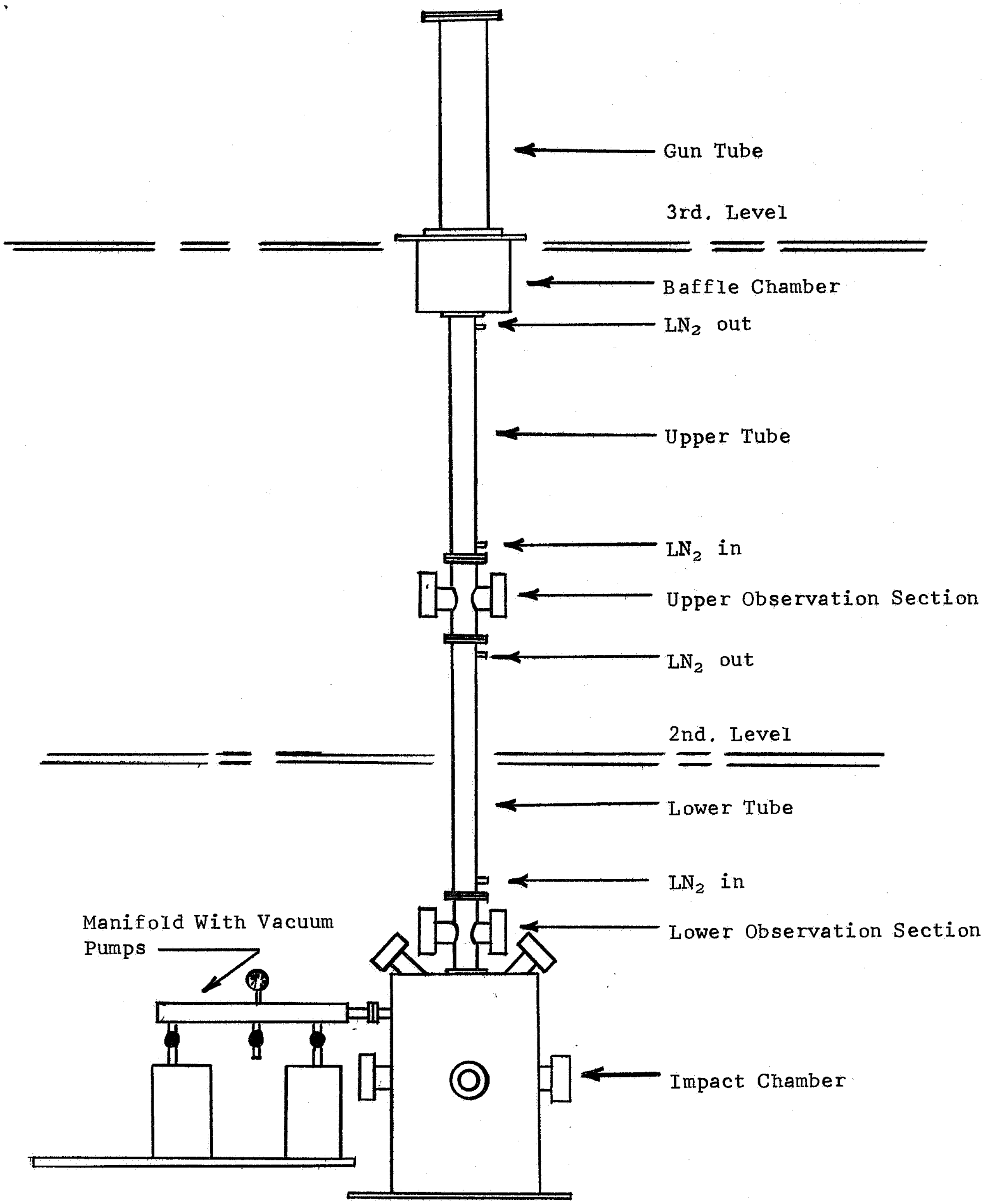
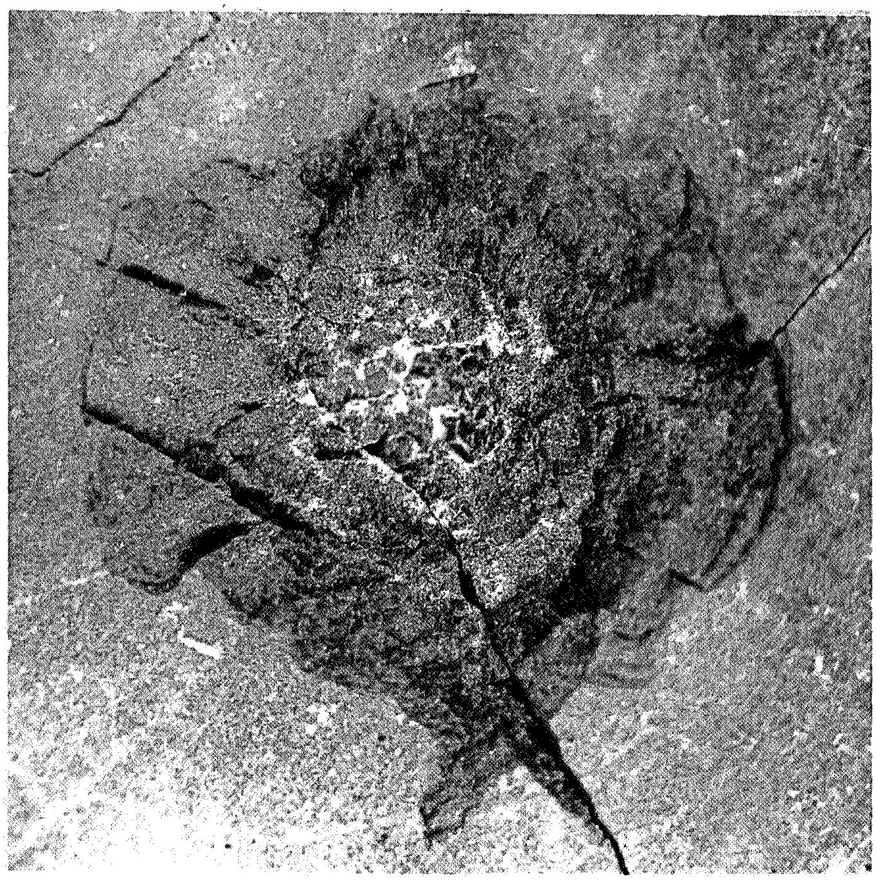
2. Maurer, W. C. and Rinehart, J. S., "Impact Crater Formation in Rock," Journal of Applied Physics, Vol 31, No. 7, July 1960 pp. 1247-1252.

3. Cannon, E. T. and Turner, G. H., "Cratering in Low-Density Targets," NASA Contractor Report NASA CR-798, June 1967.



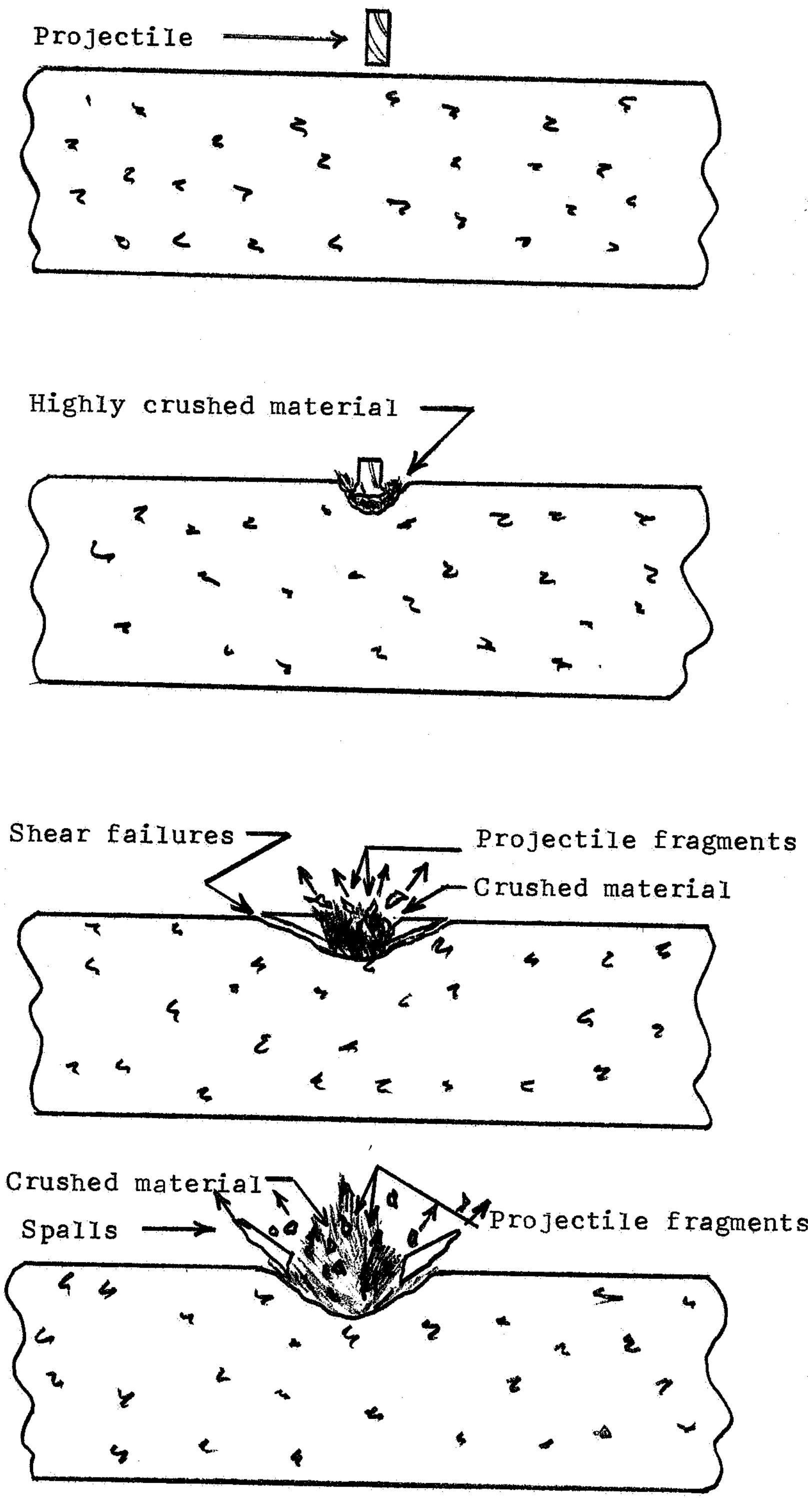
Sketch of Impact Chamber System

Fig. 1



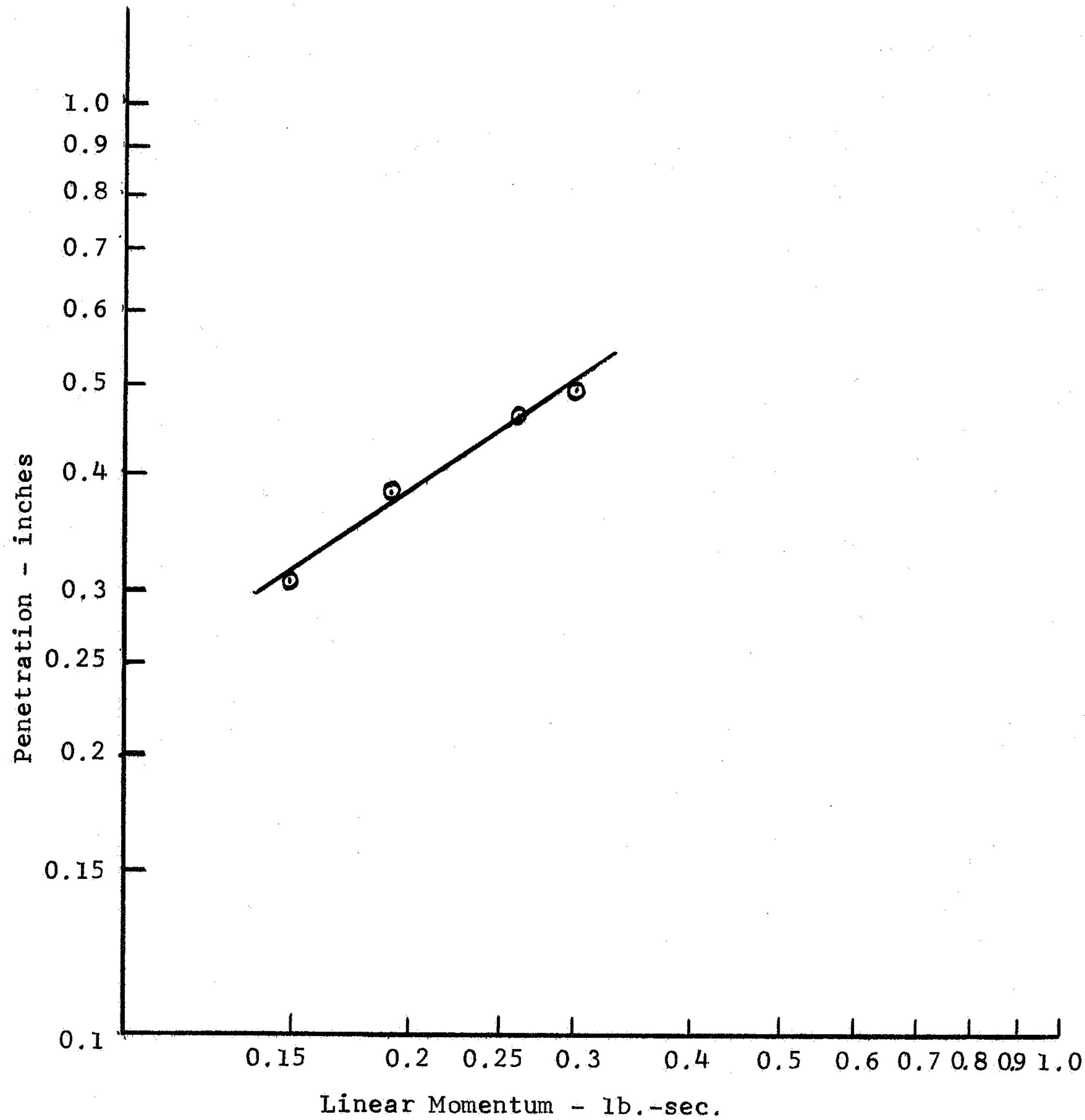
Photograph of Crater in Solid Basalt Target

Fig. 2



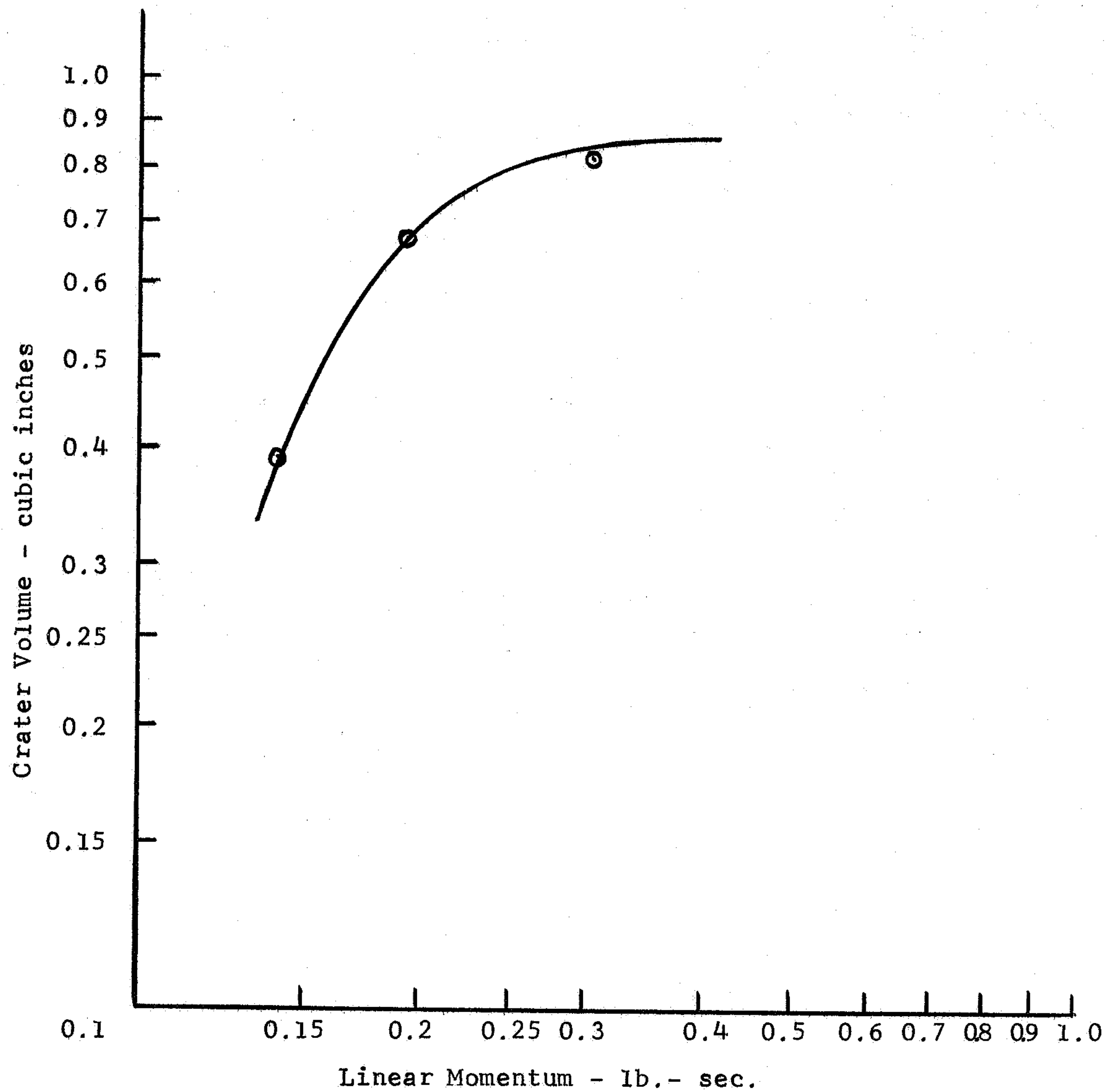
The projectile just impacts the target. Then, the projectile crushes the central target region, the crushed material pushes out spalls as the projectile splatters, and finally, the ejecta of spalls, crushed material and projectile fragments leave the crater.

Fig. 3



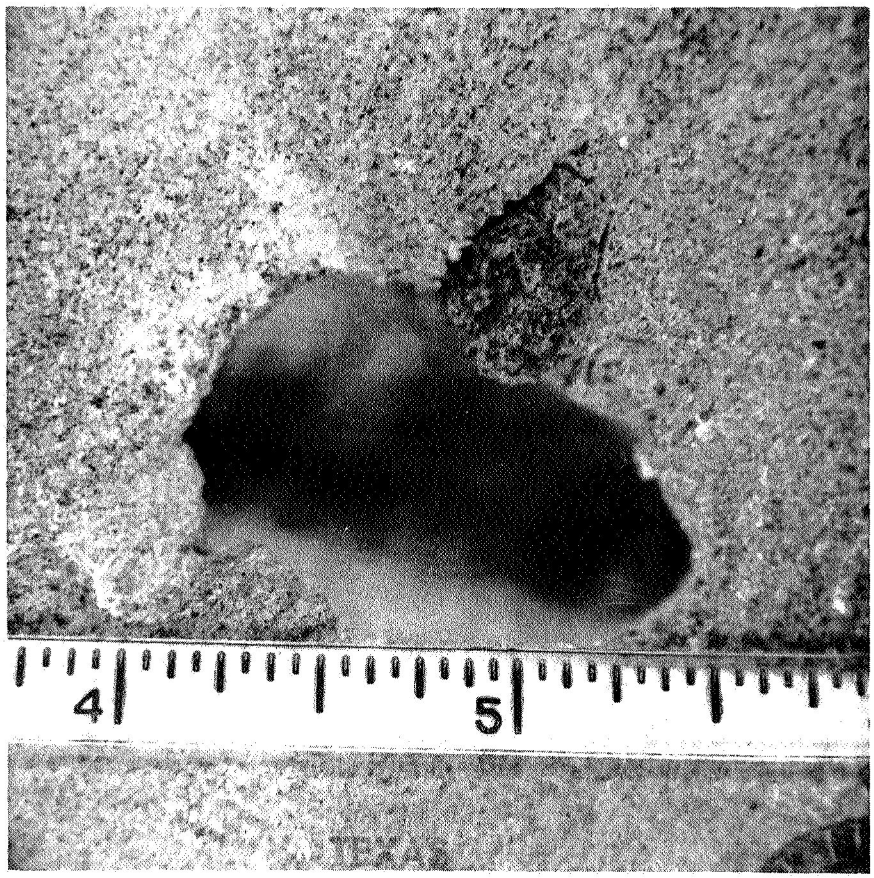
Log-log plot of penetration as a function of linear momentum for solid basalt targets

Fig. 4



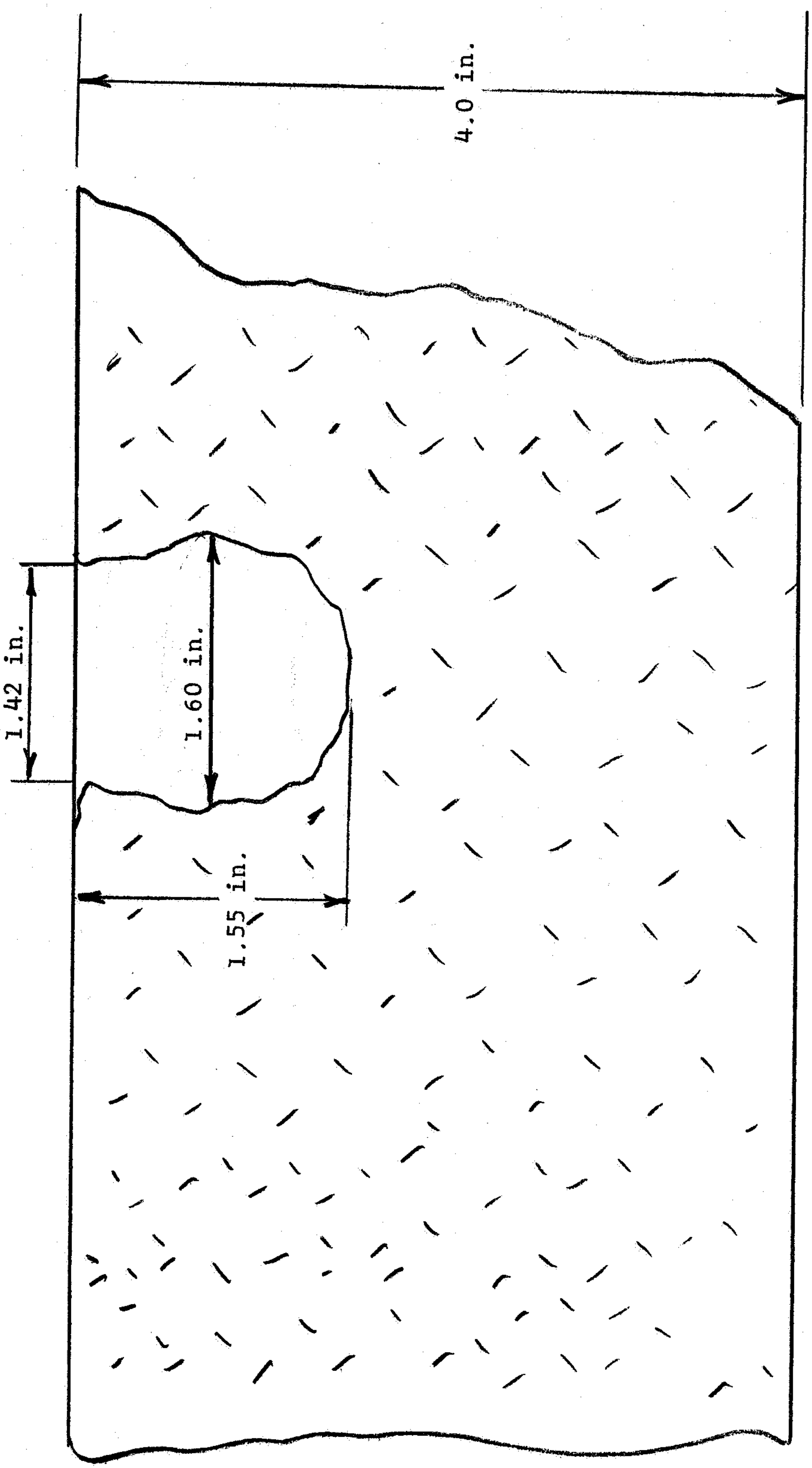
Log-log plot of crater volume as a function of linear momentum for solid basalt targets

Fig. 5



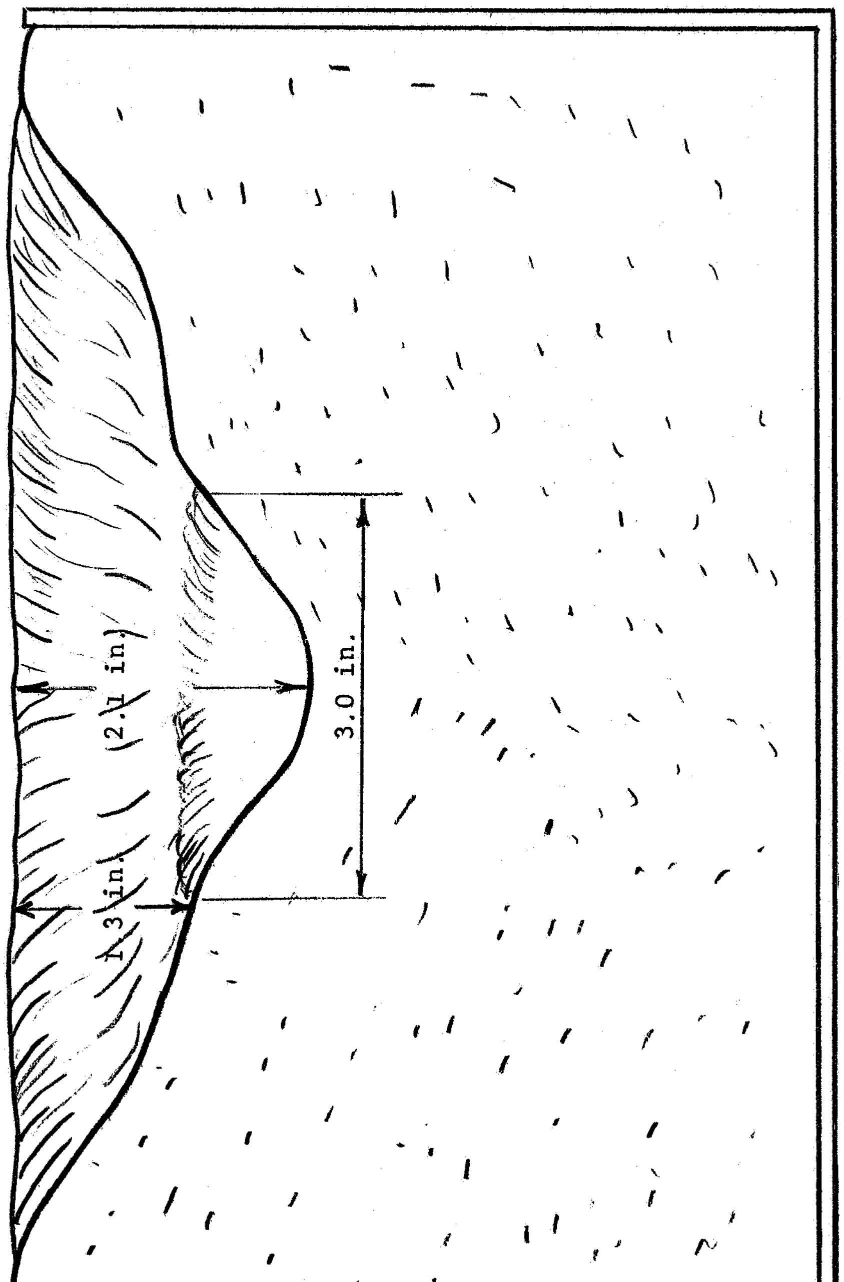
Photograph of Crater in Solid Pumice Target

Fig. 6



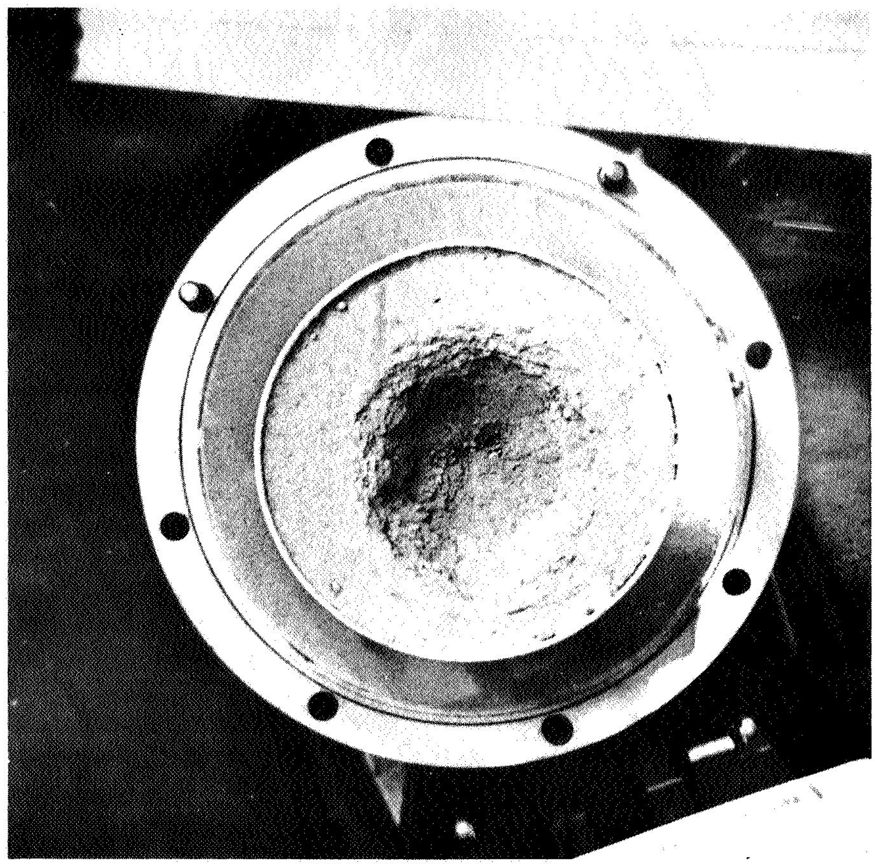
Approximate cross-section of Crater in Solid Pumice Targed. Section is along maximum diameter of entry hole.

Fig. 7



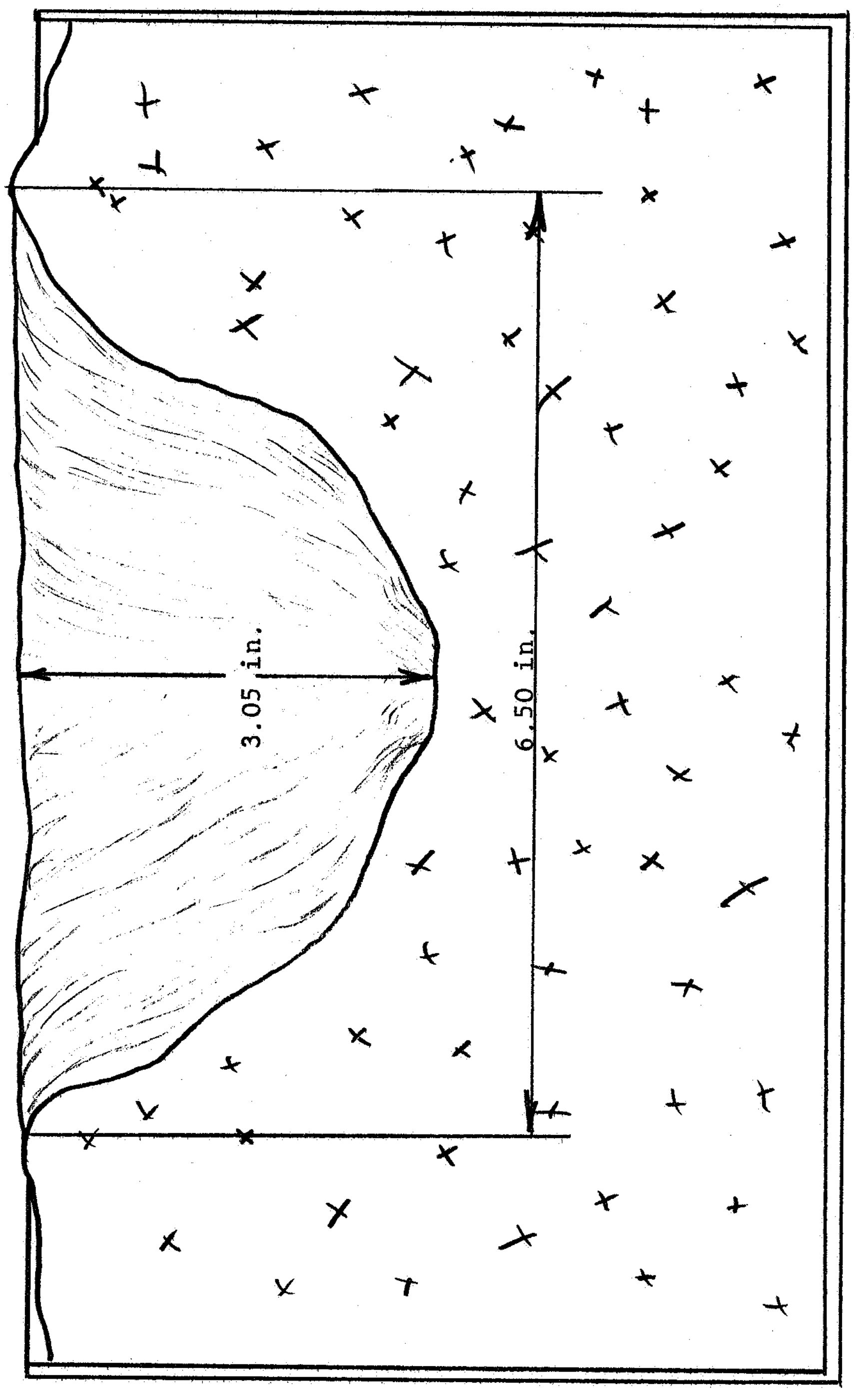
Approximate Cross-section of Crater in Coarse Granular Basalt (500-1000 microns)

Fig. 8



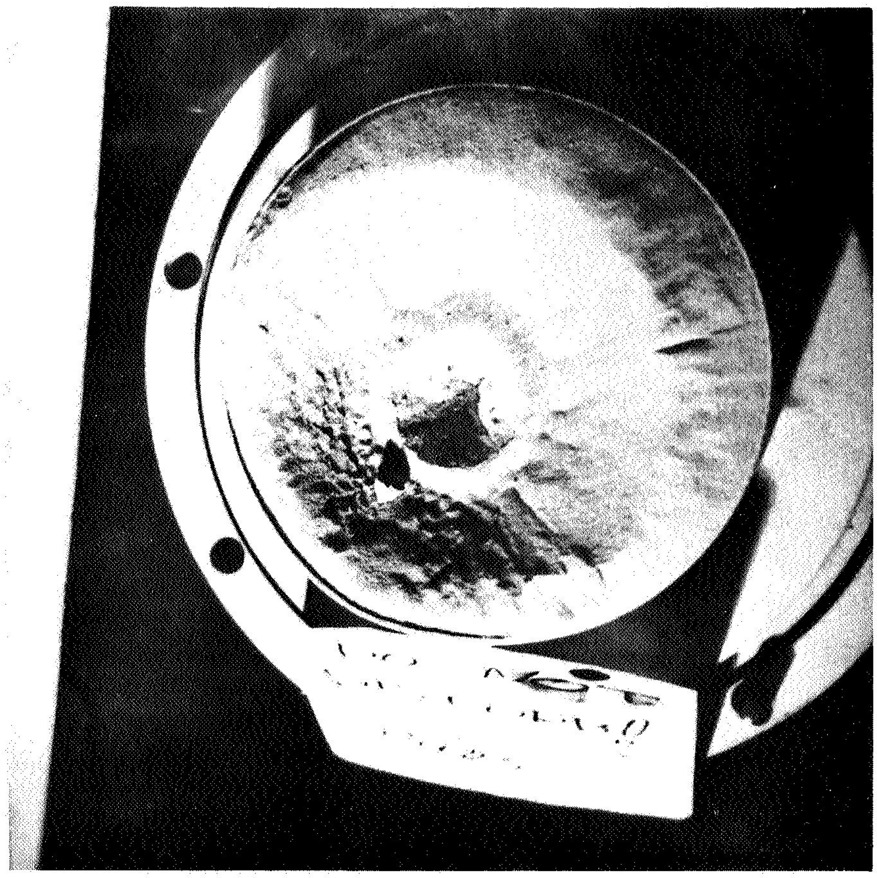
Photograph of Crater Produced in Fine Granular Basalt (62-125 micron)

Fig. 9



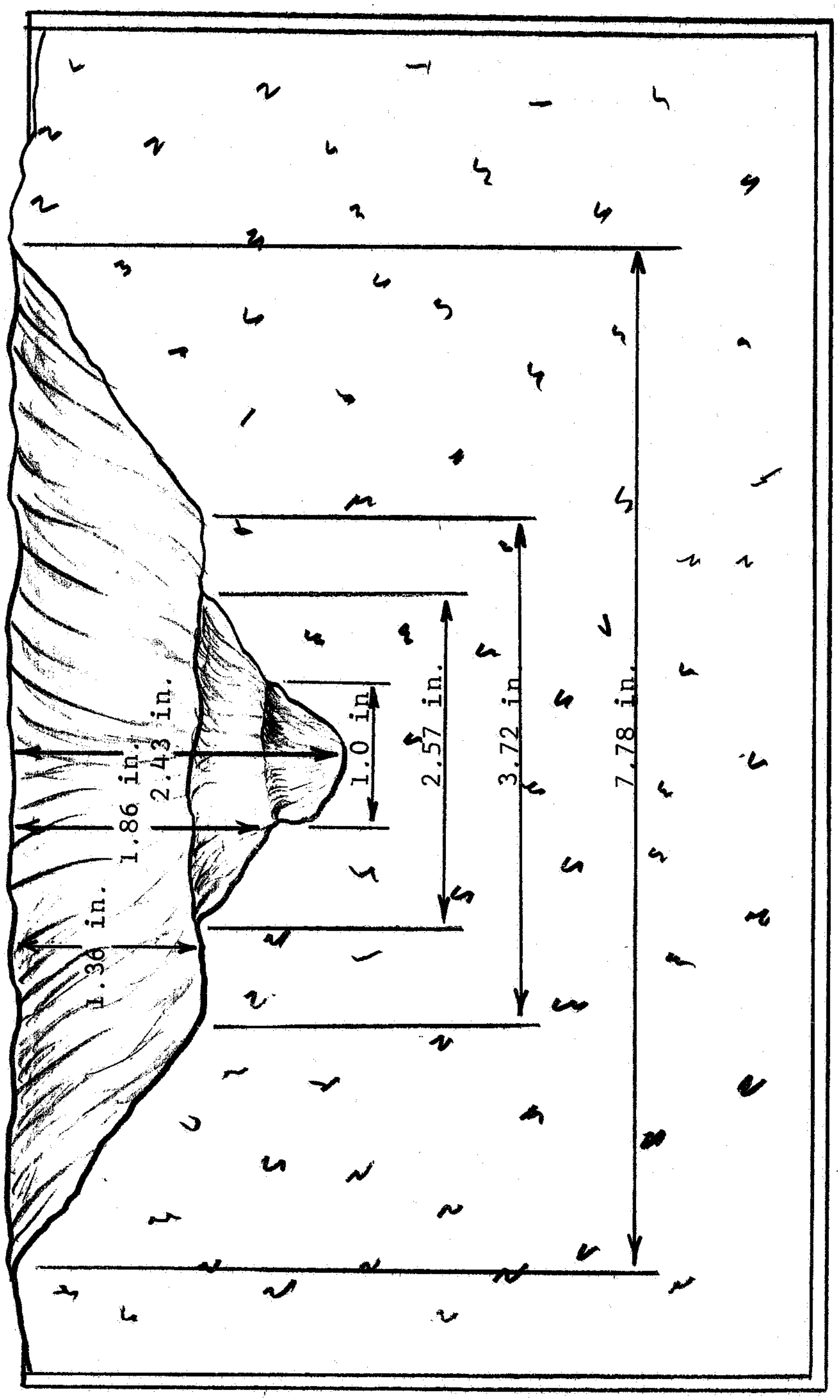
Cross-section of Crater in Fine Granular Basalt (62-125 microns)

Fig. 10



Photograph of Crater Produced in Granular Pumice (125-250 micron)

Fig. 11



Cross-section of Granular Pumice Target (125-250 microns)

Fig. 12